# $B$ and $D$ Meson Decays with Unquenched Improved Staggered Fermions

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**New Accounts:** Bernard, Hetrick, Miller, Sugar (in addition to those existing)

**Time Requested:** 270×128 P4 node-days

**Abstract**

A broad program to study leptonic and semi-leptonic decays of mesons containing a heavy quark is proposed. These calculations will allow lattice gauge theory to have much greater impact on accurate determination of CKM matrix elements from experimental results at BABAR, CLEO-c and KEK. The study will use gauge configurations that include effects of dynamical up, down and strange quarks. The heavy quark will use either the clover formulation or a new highly improved formulation under development. An improved staggered quark action (Asqtad) will be used for the light quark and should allow a much closer approach to the chiral limit than previous work.

## Scientific Program

Recent progress with improved staggered fermions has made possible unquenched calculations of much higher precision than previously achieved. Recent results from the MILC, Fermilab, and Cornell groups achieved accuracies of $2-5\%$ in such very simple quantities as $f_\pi$, $f_K$, and heavy meson masses. The achievement of similar accuracies in comparably simple but phenomenologically important quantities in $B$ and $D$ physics is an exciting prospect. This proposal is part of a larger program with the goal of providing accurate lattice results for the most important quantities in standard model phenomenology. It is one of several proposals to SciDAC that are part of this general effort. A huge experimental effort is currently devoted to $B$ and $D$ meson physics. However, the experimental measurements must be complemented by precision lattice QCD calculations of the corresponding weak matrix elements, if we are to extract accurate information for the parameters of the standard model from this effort. Hence this is a very timely project.

As explained below, we will address all sources of systematic error in our calculations, hence we expect that our results will have an unprecedented impact on CKM physics. The ultimate goal of this effort is to produce reliable results with few percent errors.

Many of us have been involved in studies of $B$ and $D$ meson quantities for many years. The main objects of our study are $B$, $B_s$, $D$, and $D_s$ mesons. In the first year we are planning to study two types of processes, purely leptonic decays, e. g., $B \to \ell\nu_\ell$, and semileptonic decays to light mesons, e. g., $B \to \pi\ell\nu_\ell$. Following that, we are planning to study other important processes, such as semileptonic decays to heavy mesons, e. g., $B \to D^*\ell\nu_\ell$, and $B$-$\bar{B}$ mixing.

Strong interaction effects in leptonic decays are characterized by the decay constants $f_B$, $f_{B_s}$, $f_D$ and $f_{D_s}$. Semileptonic decays are characterized by form factors $F(q^2)$, where $q$ is the momentum transfer carried by the leptons. Accurate lattice QCD predictions of the decay constants and form factors are needed to extract the associated CKM matrix elements from experimental measurements of $B$ and $D$ meson decays. CLEO-c will provide precise measurements of the $D$ and $D_s$ leptonic and semileptonic decays to few percent accuracy. They will take appropriate ratios of leptonic and semileptonic decay rates to cancel the dependence on CKM matrix elements. Hence, the comparison of these experimental results with lattice QCD predictions offers an unprecedented opportunity to test the lattice approach. After confirmation, this will also yield new determinations of $V_{cd}$ and $V_{cs}$. Furthermore, lattice results for $f_B$ and $f_{B_s}$ (and $B_{B_d}$ and $B_{B_s}$) will have a major impact on the determination of the poorly known CKM matrix elements $V_{td}$ and $V_{ts}$ from experimental measurements of $B$-$\bar{B}$ and $B_s$-$\bar{B}_s$ mixing. Similarly, accurate lattice determinations of semileptonic form factors for $B$ and $B_s$ mesons to light mesons would provide a new window on the CKM matrix element $V_{ub}$.

Together with these weak matrix element calculations, we will also calculate meson masses in the $B$, $B_s$, $D$, and $D_s$ meson systems. The comparison of these calculations with experimental results will give us another test of our methods, in addition to providing us with determinations of the heavy quark mass parameters.

We will be using dynamical fermion configurations generated by the MILC collaboration at two different lattice spacings, $a = 0.09$ and $0.13$ fm. These configurations have with three nondegenerate flavors of improved staggered quarks at a range of light masses, $1/8\, m_s \le m_l < m_s$. Since both the light quark and gluon actions are improved, lattice spacing errors are expected to be small.

It has recently been suggested that the size of the systematic errors associated with the chiral extrapolation in heavy-light systems may be considerably larger than previously believed. To study this effect one needs lighter quark masses, so that the chiral logarithm terms can actually be observed and included in a controlled way in the fits. Since we use improved staggered dynamical quarks, the masses of the sea quarks available to us are probably already light enough, and are certainly lighter than those of other groups. We are are planning to combine our heavy quarks with light staggered quarks, which would make it possible to construct mesons with very light $u$ and $d$ quarks. In order to obtain precise information about the chiral logarithms from these simulations, it also will be necessary to have analytic results on heavy-light decay constants from chiral perturbation theory in the presence of staggered flavor ("taste") violations. Such calculations already exist for light-light meson masses and are in progress for heavy-light decay constants.

We will start our calculations by using the clover action with the Fermilab interpretation for the heavy valence quarks. We are in the process of developing an improved action for the heavy quarks. We will use this action in the second stage of our project, at which point all quarks and gluons generated in our simulations will be highly improved. Two-loop operator renormalizations are ultimately required for high precision CKM phenomenology on the lattice. A program for accomplishing this has been begun in coordination with Howard Trottier and Matthew Nobes of Simon Fraser University. In summary, we expect that our results will have control over all systematic errors, including sea quark effects, lattice spacing errors and perturbative errors.

These calculations will require heavy quark propagators with clover or highly improved quarks and light quark propagators using the Asqtad action. These two propagators are combined together to create a meson propagator. Most of the computational effort is in the calculation of the quark propagators.

# Codes

The inverters are available from a number of sources including MILC and FermiQCD. The MILC code has been modified to write out to disk the light staggered propagators. The meson two-point function calculations are available in a CANOPY code. A test run of charmonium and $D_s$ physics is underway at Fermilab with well-established $O(a)$ improved heavy quarks and $O(a^2)$ improved light staggered quarks. The heavy quark code achieves 410 MF/processor in single precision and 250 MF/processor in double precision on the 128 dual node P4 system; the staggered code achieves 340 MF/processor on the same system. On test runs, 5.4 dual node hours were required to analyze one $20^3 \times 64$ configuration with 12 heavy quark color-spin sources, three heavy smearings, three color sources of strange staggered quark and a heavy-light analysis code. An $O(a^2)$ improved heavy quark code has been written and is being optimized. It has around an order of magnitude more floating point operations/site update, depending on which operators are included.

# Resource Allocation

The time requested is expected to be allocated approximately as follows:

- $36\times128$ P4 days for an analysis B and D masses, leptonic, and semileptonic decays on the MILC $20^3 \times 64$ data set with the $O(a)$ improved heavy quark action. This run may be partly completed by the time the proposed work begins.
- $180\times128$ P4 days for the same analysis on the MILC $28^3 \times 90$ data set.
- The remainder of the time will be for beginning the $O(a^2)$ improved run.

  Many of the light staggered propagators required for our work are the same as the ones in the related proposal by the Cornell group. More time may be made available for the $O(a^2)$ run, since light quark generation will be coordinated with them.

In its NRAC allocation, which runs from October 1, 2002 to September 30, 2003, the MILC collaboration was granted resources to study heavy-light decay constants with light Asqtad valence quarks. Those resources will be used for this project in addition to the ones requested in this proposal. We anticipate that MILC will be able to use its NSF resources to analyze a significant number of configurations from the ensembles at $a$=0.13 and 0.09, but that less than 50 percent of the available lattices would be done in the next year without SciDAC support.

# Summary

At the end of the project we expect to have the world's best determination of heavy-light meson decay constants and semileptonic decay amplitudes. They will be of key importance to the experimental programs of Fermilab, CLEO-c, BaBAR, and Belle.

The propagators generated in this proposed work will be available initially at Fermilab for projects with other physics goals. As the results for the decay constants are generated, we will endeavor to make the propagators more widely available through either the Gauge Connection or its successor. Other SciDAC researchers who need these propagators more promptly should contact one of us to arrange access.